

## SILICA-FILLED ELASTOMERIC COMPOUNDS

### FIELD OF THE INVENTION

The present invention relates to silica-filled halogenated butyl  
5 elastomers, such as bromobutyl elastomers (BIR).

### BACKGROUND OF THE INVENTION

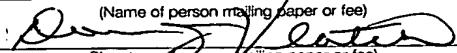
It is known that reinforcing fillers such as carbon black and silica  
greatly improve the strength and fatigue properties of elastomeric  
10 compounds. It is also known that chemical interaction occurs between the  
elastomer and the filler. For example, good interaction between carbon  
black and highly unsaturated elastomers such as polybutadiene (BR) and  
styrene butadiene copolymers (SBR) occurs because of the large number  
of carbon-carbon double bonds present in these copolymers. Butyl  
15 elastomers may have only one tenth, or fewer, of the carbon-carbon  
double bonds found in BR or SBR, and compounds made from butyl  
elastomers are known to interact poorly with carbon black. For example, a  
compound prepared by mixing carbon black with a combination of BR and  
butyl elastomers results in domains of BR, which contain most of the  
20 carbon black, and butyl domains which contain very little carbon black. It  
is also known that butyl compounds have poor abrasion resistance.

Canadian Patent Application 2,293,149 teaches that it is possible to  
produce filled butyl elastomer compositions with much improved properties  
by combining halobutyl elastomers with silica and specific silanes. These  
25 silanes act as dispersing and bonding agents between the halogenated  
butyl elastomer and the filler. However, one disadvantage of the use of  
silanes is the evolution of alcohol during the manufacturing process and  
potentially during the use of the manufactured article produced by this  
process. Additionally, silanes significantly increase the cost of the  
30 resulting manufactured article.

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Co-pending Canadian Patent Application 2,339,080 discloses filled halobutyl elastomeric compounds containing certain organic compounds containing at least one basic nitrogen-containing group and at least one hydroxyl group enhance the interaction of halobutyl elastomers with 5 carbon-black and mineral fillers, resulting in improved compound properties such as tensile strength and abrasion (DIN).

Co-pending Canadian Application CA-2,368,363 discloses filled halobutyl elastomer compositions containing halobutyl elastomers, at least one mineral filler in the presence of organic compounds containing at least 10 one basic nitrogen-containing group and at least one hydroxyl group and at least one silazane compound. However, said the CA 2,368,363 does not teach or suggest mineral fillers which are pre-modified with organic compounds containing at least one basic nitrogen-containing group and at least one hydroxyl group and silazane compounds.

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#### SUMMARY OF THE INVENTION

The present invention provides a process for preparing compositions containing halobutyl elastomers and at least one mineral filler that has been reacted with at least one organic compound containing 20 at least one basic nitrogen-containing group and at least one hydroxyl group and optionally at least one silazane compound before admixing the (pre-reacted) filler with the halobutyl elastomer. The present invention also provides a means to produce such filled compositions without the evolution of alcohol, and at significantly reduced costs, compared to 25 processes known in the art.

It has been discovered that the interaction of halobutyl elastomers with the pre-reacted filler(s) is improved, resulting in improved compound properties such as tensile strength and abrasion resistance (DIN). Compounds of this type are believed to aid in the dispersion and linking of 30 the silica to the halogenated elastomer.

Accordingly, the present invention also provides a process which includes mixing a halobutyl elastomer with at least one mineral filler that has been reacted with at least one organic compound containing at least one basic nitrogen-containing group and at least one hydroxyl group and 5 optionally with at least one silazane compound before admixing the (pre-reacted) filler with the halobutyl elastomer and curing the resulting filled halobutyl elastomer.

BRIEF DESCRIPTION OF THE DRAWINGS

10 Figure 1 illustrates the RPA Analysis of a compound prepared with HMDZ functionalized silica and a compound prepared with nonfunctionalized silica.

15 Figure 2 illustrates the stress strain profile of a compound prepared with HMDZ functionalized silica and a compound prepared with nonfunctionalized silica.

20 Figure 3 illustrates the RPA Analysis of a compound prepared with DMAE functionalized silica and a compound prepared with nonfunctionalized silica.

25 Figure 4 illustrates the stress strain profile of a compound prepared with DMAE functionalized silica and a compound prepared with nonfunctionalized silica.

Figure 5 illustrates the RPA Analysis of a compound prepared with HMDZ/DMAE functionalized silica and a compound prepared with nonfunctionalized silica.

Figure 6 illustrates the stress strain profile of a compound prepared with HMDZ/DMAE functionalized silica and a compound prepared with nonfunctionalized silica.

- 5 Figure 7 illustrates the RPA Analysis of a compound prepared with HMDZ/SAME functionalized silica and a compound prepared with nonfunctionalized silica.

- 10 Figure 8 illustrates the stress strain profile of a compound prepared with HMDZ/DMAE functionalized silica and a compound prepared with nonfunctionalized silica.

#### DETAILED DESCRIPTION OF THE INVENTION

The halobutyl elastomer that is admixed with the pre-reacted mineral filler (i.e. the filler that has been reacted with at least one organic compound containing at least one basic nitrogen-containing group and at least one hydroxyl group and optionally with at least one silazane compound) may be a mixture with another elastomer or elastomeric compound. The halobutyl elastomer should constitute more than 5% of any such mixture. Preferably the halobutyl elastomer should constitute at least 10% of any such mixture. More preferably the halobutyl elastomer constitutes at least 50% of any such mixture. In most cases it is preferred not to use mixtures but to use the halobutyl elastomer as the sole elastomer. If mixtures are to be used, however, then the other elastomer may be, for example, natural rubber, polybutadiene, styrene-butadiene or poly-chloroprene or an elastomer compound containing one or more of these elastomers.

The filled halobutyl elastomer can be cured to obtain a product which has improved properties, for instance in abrasion resistance, rolling resistance and traction. Curing can be effected with sulfur. The preferred amount of sulfur is in the range of from 0.3 to 2.0 parts by weight per

hundred parts of rubber. An activator, for example zinc oxide, may also be used, in an amount in the range of from 0.5 parts to 2 parts by weight. Other ingredients, for instance stearic acid, antioxidants, or accelerators may also be added to the elastomer prior to curing. Sulphur curing is then

5     effected in the known manner. See, for instance, chapter 2, "The Compounding and Vulcanization of Rubber", of "Rubber Technology", 3<sup>rd</sup> edition, published by Chapman & Hall, 1995, the disclosure of which is incorporated by reference with regard to jurisdictions allowing for this procedure.

10     Other curatives known to cure halobutyl elastomers may also be used. A number of compounds are known to cure halobutyl elastomers, for example, bis dieneophiles (for example m-phenyl-bis-maleamide, HVA2), phenolic resins, amines, amino-acids, peroxides, zinc oxide and the like. Combinations of the aforementioned curatives may also be used.

15     The mineral-filled halobutyl elastomer of the present invention may be admixed with other elastomers or elastomeric compounds before it is subjected to curing with sulphur.

20     The phrase "halobutyl elastomer(s)" as used herein refers to a chlorinated and/or brominated butyl elastomer. Brominated butyl elastomers are preferred, and the invention is illustrated, by way of example, with reference to such bromobutyl elastomers. It should be understood, however, that the invention particularly extends to the use of chlorinated butyl elastomers.

25     Brominated butyl elastomers may be obtained by bromination of butyl rubber (which is a copolymer of an isoolefin, usually isobutylene and a co-monomer that is usually a C<sub>4</sub> to C<sub>6</sub> conjugated diolefin, preferably isoprene – (brominated isobutene-isoprene-copolymers BIIR)). Co-monomers other than conjugated diolefins can be used, however, and mention is made of alkyl-substituted vinyl aromatic co-monomers such as

30     C<sub>1</sub>-C<sub>4</sub>-alkyl substituted styrene(s). An example of such an elastomer

which is commercially available is brominated isobutylene methylstyrene copolymer (BIMS) in which the co-monomer is p-methylstyrene.

Brominated butyl elastomers typically contain in the range of from 0.1 to 10 weight percent of repeating units derived from diolefin (preferably isoprene) and in the range of from 90 to 99.9 weight percent of repeating units derived from isoolefin (preferably isobutylene) (based upon the hydrocarbon content of the polymer) and in the range of from 0.1 to 9 weight percent bromine (based upon the bromobutyl polymer). A typical bromobutyl polymer has a molecular weight, expressed as the Mooney viscosity according to DIN 53 523 (ML 1 + 8 at 125°C), in the range of from 25 to 60.

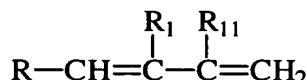
For use in the present invention the brominated butyl elastomer preferably contains in the range of from 0.5 to 5 weight percent of repeating units derived from isoprene (based upon the hydrocarbon content of the polymer) and in the range of from 95 to 99.5 weight percent of repeating units derived from isobutylene (based upon the hydrocarbon content of the polymer) and in the range of from 0.2 to 3 weight percent, preferably from 0.75 to 2.3 weight percent, of bromine (based upon the brominated butyl polymer).

A stabilizer may be added to the brominated butyl elastomer. Suitable stabilizers include calcium stearate and hindered phenols, preferably used in an amount in the range of from 0.5 to 5 parts by weight per 100 parts by weight of the brominated butyl rubber (phr).

Examples of suitable brominated butyl elastomers include Bayer 25 Bromobutyl® 2030, Bayer Bromobutyl® 2040 (BB2040), and Bayer Bromobutyl® X2 commercially available from Bayer. Bayer BB2040 has a Mooney viscosity (ML 1+8 @ 125°C) of  $39 \pm 4$ , a bromine content of  $2.0 \pm 0.3$  wt% and an approximate weight average molecular weight of 500,000 grams per mole.

30 The brominated butyl elastomer used in the process of the present invention may also be a graft copolymer of a brominated butyl rubber and

a polymer based upon a conjugated diolefin monomer. Co-pending Canadian Patent Application 2,279,085 is directed towards a process for preparing such graft copolymers by mixing solid brominated butyl rubber with a solid polymer based on a conjugated diolefin monomer which also 5 includes some C-S-(S)<sub>n</sub>-C bonds, where n is an integer from 1 to 7, the mixing being carried out at a temperature greater than 50°C and for a time sufficient to cause grafting. The disclosure of this application is incorporated herein by reference with regard to jurisdictions allowing for this procedure. The bromobutyl elastomer of the graft copolymer can be 10 any of those described above. The conjugated diolefins that can be incorporated in the graft copolymer generally have the structural formula:



wherein R is a hydrogen atom or an alkyl group containing from 1 to 8 carbon atoms and wherein R<sub>1</sub> and R<sub>11</sub> can be the same or different and 15 are selected from hydrogen atoms and alkyl groups containing from 1 to 4 carbon atoms. Some representative non-limiting examples of suitable conjugated diolefins include 1,3-butadiene, isoprene, 2-methyl-1,3-pentadiene, 4-butyl-1,3-pentadiene, 2,3-dimethyl-1,3-pentadiene 1,3-hexadiene, 1,3-octadiene, 2,3-dibutyl-1,3-pentadiene, 2-ethyl-1,3- 20 pentadiene, 2-ethyl-1,3-butadiene and the like. Conjugated diolefin monomers containing from 4 to 8 carbon atoms are preferred, 1,3-butadiene and isoprene are more preferred.

The polymer based on a conjugated diene monomer can be a homopolymer, or a copolymer of two or more conjugated diene monomers, 25 or a copolymer with a vinyl aromatic monomer.

The vinyl aromatic monomers which can optionally be used are selected so as to be copolymerizable with the conjugated diolefin monomers being employed. Generally, any vinyl aromatic monomer which is known to polymerize with organo-alkali metal initiators can be used.

Such vinyl aromatic monomers usually contain in the range of from 8 to 20 carbon atoms, preferably from 8 to 14 carbon atoms. Some examples of vinyl aromatic monomers which can be so copolymerized include styrene, alpha-methyl styrene, various alkyl styrenes including p-methylstyrene, p-

5 methoxy styrene, 1-vinylnaphthalene, 2-vinyl naphthalene, 4-vinyl toluene and the like. Styrene is preferred for copolymerization with 1,3-butadiene alone or for terpolymerization with both 1,3-butadiene and isoprene.

The halogenated butyl elastomer may be used alone or in combination with other elastomers such as:

The filler is composed of particles of a mineral, and examples include silica, silicates, clay (such as bentonite), gypsum, alumina, titanium dioxide, talc and the like, as well as mixtures thereof.

25 Further examples are:

- highly dispersable silicas, prepared e.g. by the precipitation of silicate solutions or the flame hydrolysis of silicon halides, with specific surface areas of 5 to 1000, preferably 20 to 400  $\text{m}^2/\text{g}$  (BET specific surface area), and with primary particle sizes of 10 to 400 nm; the silicas can optionally also be present as

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mixed oxides with other metal oxides such as those of Al, Mg, Ca, Ba, Zn, Zr and Ti;

- synthetic silicates, such as aluminum silicate and alkaline earth metal silicates;
- 5 - magnesium silicate or calcium silicate, with BET specific surface areas of 20 to 400 m<sup>2</sup>/g and primary particle diameters of 10 to 400 nm;
- natural silicates, such as kaolin and other naturally occurring silica;
- 10 - glass fibres and glass fibre products (matting, extrudates) or glass microspheres;
- metal oxides, such as zinc oxide, calcium oxide, magnesium oxide and aluminum oxide;
- metal carbonates, such as magnesium carbonate, calcium carbonate and zinc carbonate;
- 15 - metal hydroxides, e.g. aluminum hydroxide and magnesium hydroxide;

or combinations thereof.

Some mineral particles have hydroxyl groups on their surface, 20 rendering them hydrophilic and oleophobic. This exacerbates the difficulty of achieving good interaction between the filler particles and the butyl elastomer. For many purposes, the preferred mineral is silica, especially silica prepared by the carbon dioxide precipitation of sodium silicate.

Dried amorphous silica particles suitable for use in accordance with 25 the present invention have a mean agglomerate particle size in the range of from 1 to 100 microns, preferably between 10 and 50 microns and more preferably between 10 and 25 microns. It is preferred that less than 10 percent by volume of the agglomerate particles are below 5 microns or over 50 microns in size. A suitable amorphous dried silica moreover has a 30 BET surface area, measured in accordance with DIN (Deutsche Industrie Norm) 66131, of between 50 and 450 square meters per gram and a DBP

absorption, as measured in accordance with DIN 53601, of between 150 and 400 grams per 100 grams of silica, and a drying loss, as measured according to DIN ISO 787/11, of from 0 to 10 percent by weight. Suitable silica fillers are available under the trademarks HiSil® 210, HiSil® 233 and

5 HiSil® 243 from PPG Industries Inc. Also suitable are Vulkasil S and Vulkasil N, from Bayer AG (Vulkasil is a registered trademark of Bayer AG).

Those mineral filler may be used in combination with known non-mineral fillers, such as

10 - carbon blacks; the carbon blacks to be used here are prepared by the lamp black, furnace black or gas black process and have BET specific surface areas of 20 to 200 m<sup>2</sup>/g, e.g. SAF, ISAF, HAF, FEF or GPF carbon blacks;

or

15 - rubber gels, especially those based on polybutadiene, butadiene/styrene copolymers, butadiene/acrylonitrile copolymers and polychloroprene.

Non-mineral fillers are not normally used as filler in the halobutyl elastomer compositions of the present invention, they may be present in

20 an amount up to 40 phr. In these cases, it is preferred that the mineral filler should constitute at least 55% by weight of the total amount of filler. If the halobutyl elastomer composition of the present invention is blended with another elastomeric composition, that other composition may contain mineral and/or non-mineral fillers.

25 The silazane compound can have one or more silazane groups, e.g. disilazanes. Organic silazane compounds are preferred. Examples include but are not limited to Hexamethyldisilazane (HDMZ), Heptamethyl-disilazane, 1,1,3,3-Tetramethyldisilazane, 1,3-bis(Chloromethyl)-tetramethyldisilazane, 1,3-Divinyl-1,1,3,3-tetramethyldisilazane, and 1,3-

30 Diphenyltetramethyldisilazane.

The organic compound containing at least one basic nitrogen-containing group and at least one hydroxyl group is not limited to a special class of compounds. Examples include proteins, aspartic acid, 6-aminocaproic acid, and other compounds comprising an amino and an

5 alcohol function, such as diethanolamine and triethanolamine. Preferably, the organic compound containing at least one basic nitrogen-containing group and at least one hydroxyl group comprises a primary alcohol group and an amine group separated by methylene bridges, the methylene bridges may be branched. Such compounds have the general formula

10 HO-A-NH<sub>2</sub>; wherein A represents a C<sub>1</sub> to C<sub>20</sub> alkylene group, which may be linear or branched.

More preferably, the number of methylene groups between the two functional groups should be in the range of from 1 to 4. Examples of preferred additives include monoethanolamine and N,N-dimethylamino-15 ethanol (DMAE).

The amount of pre-reacted filler to be incorporated into the halobutyl elastomer can vary between wide limits. Typical amounts of the filler range from 20 parts to 250 parts by weight, preferably from 30 parts to 100 parts, more preferably from 40 to 80 parts per hundred parts of 20 elastomer. In cases where a silazane compound is present, the amount of the silazane compound contained in the filler is typically in the range of from 0.3 to 10 parts per hundred parts of elastomer, preferably of from 0.5 to 6, more preferably of from 1 to 5 parts per hundred parts of elastomer. The amount of hydroxyl- and amine-containing compound contained in the 25 filler is typically in the range of from 0.5 to 10 parts per hundred parts of elastomer, preferably of from 1 to 3 parts per hundred parts of elastomer. The mineral filler is reacted with at least one organic compound containing at least one basic nitrogen-containing group and at least one hydroxyl group and optionally at least one silazane compound before admixing the 30 resulting pre-reacted filler with the elastomer(s). The reaction between filler and the organic compound(s) containing at least one basic nitrogen-

containing group and at least one hydroxyl group and optionally the silazane compound(s) (filler derivatization reaction) is effected by suspending the mineral filler (e.g. a silica such as HiSil® 233) in organic diluents (e.g. hexane) with rapid agitation. Once a stable suspension is

5 obtained, the appropriate levels of the organic compound(s) containing at least one basic nitrogen-containing group and at least one hydroxyl group and optionally silazane compound(s) and/or optionally further additives is added. After completion of the reaction (preferably after 8 hours), the pre-reacted filler is separated from the organic phase and dried (optionally in

10 vacuum to a constant weight).

Furthermore up to 40 parts of processing oil, preferably from 5 to 20 parts, per hundred parts of elastomer, may be present in the final mixture comprising pre-reacted filler and elastomer(s). Further, a lubricant, for example a fatty acid such as stearic acid, may be present in an amount up to 15 3 parts by weight, more preferably in an amount up to 2 parts by weight.

The halobutyl elastomer(s), pre-reacted filler(s) and optionally other filler(s) are mixed together, suitably at a temperature in the range of from 25 to 200°C. It is preferred that the temperature in one of the mixing stages be greater than 60°C, and a temperature in the range of from 90 to

20 150°C is more preferred. Normally the mixing time does not exceed one hour; a time in the range from 2 to 30 minutes is usually adequate. The mixing is suitably carried out on a two-roll mill mixer, which provides good dispersion of the filler within the elastomer. Mixing may also be carried out in a Banbury mixer, or in a Haake or Brabender miniature internal mixer.

25 An extruder also provides good mixing, and has the further advantage that it permits shorter mixing times. It is also possible to carry out the mixing in two or more stages. Further, the mixing can be carried out in different apparatuses, for example one stage may be carried out in an internal mixer and another in an extruder.

The enhanced interaction between the filler and the halobutyl elastomer results in improved properties for the filled elastomer. These improved properties include higher tensile strength, higher abrasion resistance, lower permeability and better dynamic properties. These 5 render the filled elastomers suitable for a number of applications, including, but not limited to, use in tire treads and tire sidewalls, tire innerliners, tank linings, hoses, rollers, conveyor belts, curing bladders, gas masks, pharmaceutical enclosures and gaskets.

According to the present invention, bromobutyl elastomer, pre-reacted silica particles and optionally, processing oil extender can be 10 mixed on a two-roll mill at a nominal mill temperature of 25°C. The mixed compound can then placed on a two-roll mill and mixed at a temperature above 60°C. It is preferred that the temperature of the mixing is not too high, and more preferably does not exceed 150°C, since higher 15 temperatures may cause curing to proceed undesirably far and thus impede subsequent processing. The product of mixing these four ingredients at a temperature not exceeding 150°C is a compound which has good stress/strain properties and which can be readily processed further on a warm mill with the addition of curatives.

20 The filled halobutyl rubber compositions of the present invention, such as filled bromobutyl rubber compositions, find many uses, but mention is made particularly of use in tire tread compositions.

The invention is further illustrated in the following examples.

## EXAMPLES

### Description of tests:

5        *Abrasion resistance:*

DIN 53-516 (60 grit Emery paper)

*Dynamic Property Testing:*

RPA measurements were obtained with the use of an Alpha Technologies

RPA 2000 operating at 100 °C at a frequency of 6 cpm. Strain sweeps

10      were measured at strains of 0.1, 0.2, 0.5, 1, 2, 5, 10, 20, 50 and 90 °.

Stress-strain samples were prepared by curing a macro sheet at 170 °C for tc90+5 minutes, after which the appropriate sample was dyed out. The test was conducted at 70 °C.

*Cure rheometry:*

15      ASTM D 52-89 MDR2000E Rheometer at 1° arc and 1.7 Hz

### Description of Ingredients and General Mixing Procedure:

Hi-Sil® 233 - silica - a product of PPG

Sunpar® 2280 - paraffinic oil produced by Sun Oil

20      Maglite® D - magnesium oxide produced by CP Hall

The brominated butyl elastomer (in all cases commercial Bayer®

Bromobutyl 2030) silica, oil and pre-reacted filler were mixed on either:

25      i)      a tangential Banbury internal mixer operating at 77 rpm while being thermally regulated with the use of a Mokon set to 40 °C.

Compounds were mixed for a total of 6 minutes. The final rubber temperature ranged from 140 °C to 180 °C.

ii)      a 10" x 20" two-roll mill with the rolls running at 24 and 32 rpm. The mill roll was set at 25°C, with a total incorporation time of 10

30      minutes. The mixed compounds were then "heat treated" for a

further 10 minutes with the roll temperature at 110°C. The final rubber temperature was 125°C.

Curatives were then added to the cooled sample with the mill at 25°C.

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### Examples 1a and 1b (comparative)

The following examples illustrates the use of HMDZ functionalized silica in a Bromobutyl compound (1a) in comparison to use of non-functionalized silica in a Bromobutyl compound (1b). The functionalized silica was prepared by suspending HiSil® 233 in hexanes with rapid agitation. Once a stable suspension was obtained, the specified amount of HMDZ was added with the use of a disposable syringe. The functionalization reaction was allowed to proceed, under agitation, for 8 hours. At this point, the silica was separated from the organic phase and dried, at 60°C, to a constant weight. The Bromobutyl compounds (1a) and (1b) subsequently prepared with functionalized (1a) and non-functionalized (1b) silica were mixed with the use of a 10" x 20" mill. The compounding procedure involved mixing the Bromobutyl (BB2030) with the silica on a 10" x 20" mill at room temperature. Once the silica was incorporated into the BB2030, the compounds were heat treated on the mill at a temperature of 110°C. The curatives (sulfur, stearic acid and zinc oxide) were subsequently added at room temperature with the use of a 10" x 20" mill. The details associated with the preparation of the silica and subsequent Bromobutyl compound can be found in Table 1.

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The physical properties of the resulting compounds are presented in Table 2. As can be seen from this data, the use of HMDZ functionalized silica (1a) significantly decreases the DIN abrasion volume loss of this compound compared to the control compound (1b) which was prepared in an analogous manner, but with the use of unmodified HiSil 233.

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Interestingly, the compound prepared with HMDZ functionalized silica was found to possess a longer t03 time (indication of Mooney scorch, the larger

the t03 time the better the scorch safety) than that found for the control compound.

RPA Analysis (Figure 1) of the compound prepared with HMDZ functionalized silica revealed a significant improvement in filler distribution 5 as evidenced by the lower value of  $G^*$  at low strains as compared to the control compound based on unmodified HiSil 233. The stress-strain profile (Figure 2) revealed little difference between this compound and the control.

10 **Examples 2a (according to the invention) and 2b (comparative)**

The following examples illustrates the use of DMAE functionalized silica in a Bromobutyl compound (2a) in comparison to use of non-functionalized silica in a Bromobutyl compound (2b). The functionalized silica was prepared by suspending HiSil® 233 in hexanes with rapid 15 agitation. Once a stable suspension was obtained, the specified amount of DMAE was added with the use of a disposable syringe. The functionalization reaction was allowed to proceed, under agitation, for 8 hours. At this point, the silica was separated from the organic phase and dried, at 60°C, to a constant weight. The Bromobutyl compounds 20 subsequently prepared with functionalized silica (2a) and non-functionalized silica (2b) were mixed with the use of a 10" x 20" mill. The compounding procedure involved mixing the Bromobutyl (BB2030) with the silica on a 10" x 20" mill at room temperature. Once the silica was incorporated into the BB2030, the compounds were heat treated on the 25 mill at a temperature of 110°C. The curatives (sulfur, stearic acid and zinc oxide) were subsequently added at room temperature with the use of a 10" x 20" mill. The details associated with the preparation of the silica and subsequent Bromobutyl compounds can be found in Table 3.

The physical properties of the resulting compounds are presented 30 in Table 4. As can be seen from this data, the use of DMAE functionalized silica significantly decreases the DIN abrasion volume loss of this

compound compared to the control compound which was prepared in an analogous manner, but with the use of unmodified HiSil 233 and compound 1a. The compound prepared with DMAE functionalized silica was found to possess a  $t_{03}$  time only slightly lower than that found for the 5 control compound. This  $t_{03}$  time is, however, significantly longer than that observed for compounds in which DMAE is added to a mixture of BB2030 and HiSil 233 via conventional mixing approaches (see Co-pending Canadian Patent Application 2,339,080)

RPA Analysis (Figure 3) of the compound prepared with DMAE 10 functionalized silica revealed a significant improvement in filler distribution as evidenced by the lower value of  $G^*$  at low strains as compared to the control compound based on unmodified HiSil 233. The stress-strain profile (Figure 4) revealed a substantial improvement in the degree of reinforcement when compared to that observed for the control compound.

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**Examples 3a (according to the invention) and 3b (comparative)**

The following examples illustrate the use of HMDZ/DMAE functionalized silica (at levels which correspond to 1.45 phr of HMDZ and 2.8 phr of DMAE as found in the final bromobutyl compound) in a 20 Bromobutyl compound (3a) in comparison to use of non-functionalized silica in a Bromobutyl compound (3b). The functionalized silica was prepared by suspending HiSil 233 in hexanes with rapid agitation. Once a stable suspension was obtained, the specified amount of HMDZ and DMAE was added with the use of a disposable syringe. The 25 functionalization reaction was allowed to proceed, under agitation, for 8 hours. At this point, the silica was separated from the organic phase and dried, at 60°C, to a constant weight. The Bromobutyl compounds subsequently prepared with functionalized silica (3a) and non-functionalized silica (3b) were mixed with the use of a 10" x 20" mill. The 30 compounding procedures involved mixing the Bromobutyl (BB2030) with the silica on a 10" x 20" mill at room temperature. Once the silica was

incorporated into the BB2030, the compounds were heat treated on the mill at a temperature of 110°C. The curatives (sulfur, stearic acid and zinc oxide) were subsequently added at room temperature with the use of a 10" x 20" mill. The details associated with the preparation of the silica and 5 subsequent Bromobutyl compounds can be found in Table 5.

The physical properties of the resulting compounds are presented in Table 6. As can be seen from this data, the use of HMDZ/DMAE functionalized silica significantly decreases the DIN abrasion volume loss of this compound compared to the control compound which was prepared 10 in an analogous manner, but with the use of unmodified HiSil 233 and compound 1a and 2a. Importantly, the compound prepared with HMDZ/DMAE functionalized silica was found to possess a longer  $t_{03}$  time when compared to that found for the control compound. As in the previous example, this  $t_{03}$  time is significantly longer than that observed for 15 compounds in which HMDZ and DMAE are added to a mixture of BB2030 and HiSil 233 via conventional mixing approaches (see Co-pending Canadian Patent Application 2,339,080)

RPA Analysis (Figure 5) of the compound prepared with HMDZ/DMAE functionalized silica revealed a significant improvement in 20 filler distribution as evidenced by the lower value of  $G^*$  at low strains as compared to the control compound based on unmodified HiSil 233. Importantly, the degree of filler distribution appears to be enhanced with 25 silica which has been modified with both HMDZ and DMAE (c.f. Example 1 and Example 2). The stress-strain profile (Figure 6) revealed a substantial improvement in the degree of re-inforcement when compared to that observed for the control compound.

#### **Example 4a (according to the invention) and 4b (comparative)**

The following examples illustrate the use of HMDZ/DMAE 30 functionalized silica (at levels which correspond to 1.45 phr of HMDZ and 3.0 phr of DMAE as found in the final bromobutyl compound) in a

Bromobutyl compound (4a) in comparison to use of non-functionalized silica in a Bromobutyl compound (4b). The functionalized silica was prepared by suspending HiSil 233 in hexanes with rapid agitation. Once a stable suspension was obtained, the specified amount of HMDZ and

5 DMAE was added with the use of a disposable syringe. The functionalization reaction was allowed to proceed, under agitation, for 8 hours. At this point, the silica was separated from the organic phase and dried, at 60°C, to a constant weight. The Bromobutyl compounds subsequently prepared with functionalized silica (4a) and non-

10 functionalized silica (4b) were mixed with the use of a 10" x 20" mill. The compounding procedure involved mixing the Bromobutyl (BB2030) with the silica on a 10" x 20" mill at room temperature. Once the silica was incorporated into the BB2030, the compounds were heat treated on the mill at a temperature of 110°C. The curatives (sulfur, stearic acid and zinc

15 oxide) were subsequently added at room temperature with the use of a 10" x 20" mill. The details associated with the preparation of the silica and subsequent Bromobutyl compounds can be found in Table 7.

The physical properties of the resulting compounds are presented in Table 8. As can be seen from this data, the use of HMDZ/DMAE

20 functionalized silica significantly decreases the DIN abrasion volume loss of this compound compared to the control compound which was prepared in an analogous manner, but with the use of unmodified HiSil 233 and compounds 1a and 2a. Importantly, the compound prepared with HMDZ/DMAE functionalized silica was found to possess a longer t03 time

25 when compared to that found for the control compound. As in the previous example, this t03 time is significantly longer than that observed for compounds in which HMDZ and DMAE are added to a mixture of BB2030 and HiSil 233 via conventional mixing approaches (see Co-pending Canadian Patent Application 2,339,080)

30 RPA Analysis (Figure 7) of the compound prepared with DMAE functionalized silica revealed a significant improvement in filler distribution

as evidenced by the lower value of  $G^*$  at low strains as compared to the control compound based on unmodified HiSil 233. Importantly, the degree of filler distribution appears to be enhanced with silica which has been modified with both HMDZ and DMAE (c.f. Example 1 and Example 2).

5 The stress-strain profile (Figure 8) revealed a substantial improvement in the degree of re-inforcement when compared to that observed for the control compound.

The examples detailed above serve to illustrate the advantages of using pre-functionalized silica in Bromobutyl compounds. Compounds

10 prepared with HMDZ functionalized silica were found to possess enhanced levels of filler dispersion, abrasion resistance (DIN) and scorch safety. However, the best results were obtained with compounds which were prepared with either DMAE or HMDZ/DMAE functionalized silica. Specifically, the best balance of properties were obtained with either  
 15 DMAE or HMDZ/DMAE modified silica.

**Table 1**

Silica Preparation		
Silica Modifier	2.9 HMDZ	None
Example	<b>1a</b>	<b>1b</b>
HiSil 233 (g)	446.53	446.53
Hexanes (mL)	3000 mL	3000 mL
DMAE (mL)	0	0
HMDZ (mL)	28.21	0
Bromobutyl Compound		
	PHR	PHR
BB2030	100	100
Silica	60	60
Sulfur	0.5	0.5
Stearic Acid	1	1
ZnO	1.5	1.5

Tabl 2

STRESS STRAIN (DUMBBELLS)		
Example	1b	1a
Silica Modifier	None	2.9 HMDZ
Cure Time (min)	43	24
Cure Temperature (°C)	170	170
Dumbbell	Die C	Die C
Test Temperature (°C)	23	23
Hardness Shore A2 (pts.)	67	63
Ultimate Tensile (MPa)	7.56	16.14
Ultimate Elongation (%)	715	530
Stress @ 25 (MPa)	1.43	1.11
Stress @ 50 (MPa)	1.36	1.26
Stress @ 100 (MPa)	1.35	1.61
Stress @ 200 (MPa)	1.75	3.15
Stress @ 300 (MPa)	2.57	6.45
DIN ABRASION		
Abrasion Volume Loss (mm <sup>3</sup> )	418	225
COMPOUND MOONEY SCORCH		
Test Temperature (°C)	135	135
t Value t03 (min)	15.31	>30
t Value t18 (min)	>30	>30
MDR CURE CHARACTERISTICS		
Frequency (Hz)	1.7	1.7
Test Temperature (°C)	170	170
Degree Arc (°)	1	1
Test Duration (min)	60	60
Torque Range (dN.m)	100	100
Chart No.	654	2077
MH (dN.m)	26.14	23.41
ML (dN.m)	13.8	5.49
Delta MH-ML (dN.m)	12.34	17.92
ts 1 (min)	0.3	0.9
ts 2 (min)	0.36	1.62
t' 10 (min)	0.27	1.42
t' 25 (min)	0.47	3.37
t' 50 (min)	4.14	6.52
t' 90 (min)	37.47	19.4
t' 95 (min)	48.01	24.33
Delta t'50 - t'10 (min)	3.87	5.1

Tabl 3

Silica Preparation		
Silica Modifier	3.2 DMAE	None
Example	<b>2a</b>	<b>2b</b>
HiSil 233 (g)	447.11	447.11
Hexanes (mL)	3000 mL	3000 mL
DMAE (mL)	26.88	0
HMDZ (mL)	0	0
Bromobutyl Compound		
	PHR	PHR
BB2030	100	100
Silica	60	60
Sulfur	0.5	0.5
Stearic Acid	1	1
ZnO	1.5	1.5

Tabl 4

STRESS STRAIN (DUMBBELLS)		
Example	2b	2a
Silica Modifier	None	3.2 DMAE
Cure Time (min)	43	24
Cure Temperature (°C)	170	170
Dumbell	Die C	Die C
Test Temperature (°C)	23	23
Hardness Shore A2 (pts.)	67	53
Ultimate Tensile (MPa)	7.56	19.9
Ultimate Elongation (%)	715	440
Stress @ 25 (MPa)	1.43	0.911
Stress @ 50 (MPa)	1.36	1.26
Stress @ 100 (MPa)	1.35	2.13
Stress @ 200 (MPa)	1.75	6.03
Stress @ 300 (MPa)	2.57	12.37
DIN ABRASION		
Abrasion Volume Loss (mm <sup>3</sup> )	418	152
COMPOUND MOONEY SCORCH		
Test Temperature (°C)	135	135
t Value t03 (min)	15.31	12.83
t Value t18 (min)	>30	20.28
MDR CURE CHARACTERISTICS		
Frequency (Hz)	1.7	1.7
Test Temperature (°C)	170	170
Degree Arc (°)	1	1
Test Duration (min)	60	60
Torque Range (dN.m)	100	100
Chart No.	654	2082
MH (dN.m)	26.14	22.89
ML (dN.m)	13.8	6.54
Delta MH-ML (dN.m)	12.34	16.35
ts 1 (min)	0.3	1.32
ts 2 (min)	0.36	2.28
t' 10 (min)	0.27	1.92
t' 25 (min)	0.47	3.74
t' 50 (min)	4.14	7.17
t' 90 (min)	37.47	19.07
t' 95 (min)	48.01	22.96
Delta t'50 - t'10 (min)	3.87	5.25

**Table 5**

Silica Preparation		
Silica Modifier Example	1.45 HMDZ/2.8 DMAE 3a 442.54	None 3b 442.54
HiSil 233 (g)	3000 mL	3000 mL
Hexanes (mL)	23.28	0
DMAE (mL)	14.08	0
Bromobutyl Compound		
BB2030	PHR 100	PHR 100
Silica	60	60
Sulfur	0.5	0.5
Stearic Acid	1	1
ZnO	1.5	1.5

Tabl 6

STRESS STRAIN (DUMBBELLS)		
Example	3b	3a
Silica Modifier	None	1.45 HMDZ/2.8 DMAE
Cure Time (min)	43	28
Cure Temperature (°C)	170	170
Dumbell	Die C	Die C
Test Temperature (°C)	23	23
Hardness Shore A2 (pts.)	67	49
Ultimate Tensile (MPa)	7.56	20.83
Ultimate Elongation (%)	715	553
Stress @ 25 (MPa)	1.43	0.765
Stress @ 50 (MPa)	1.36	1.02
Stress @ 100 (MPa)	1.35	1.61
Stress @ 200 (MPa)	1.75	4.29
Stress @ 300 (MPa)	2.57	9.45
DIN ABRASION		
Abrasion Volume Loss (mm <sup>3</sup> )	418	208
COMPOUND MOONEY SCORCH		
Test Temperature (°C)	135	135
t Value t03 (min)	15.31	>30
t Value t18 (min)	>30	>30
MDR CURE CHARACTERISTICS		
Frequency (Hz)	1.7	1.7
Test Temperature (°C)	170	170
Degree Arc (°)	1	1
Test Duration (min)	60	60
Torque Range (dN.m)	100	100
Chart No.	654	2083
MH (dN.m)	26.14	18.55
ML (dN.m)	13.8	4.75
Delta MH-ML (dN.m)	12.34	13.8
ts 1 (min)	0.3	1.62
ts 2 (min)	0.36	3.42
t' 10 (min)	0.27	2.28
t' 25 (min)	0.47	5.19
t' 50 (min)	4.14	9.55
t' 90 (min)	37.47	23.04
t' 95 (min)	48.01	27.77
Delta t'50 - t'10 (min)	3.87	7.27

Tabl 7

Silica Preparation		
Silica Modifier Example	1.45 HMDZ/3.0 DMAE 4a 441.84	None 4b 441.84
HiSil 233 (g)	3000 mL	3000 mL
Hexanes (mL)	24.91	0
DMAE (mL)	14.05	0
Bromobutyl Compound		
BB2030	PHR 100	PHR 100
Silica	60	60
Sulfur	0.5	0.5
Stearic Acid	1	1
ZnO	1.5	1.5

Tabl 8

STRESS STRAIN (DUMBBELLS)		
Example	4b	4a
Silica Modifier	None	1.45 HMDZ/3.0 DMAE
Cure Time (min)	43	28
Cure Temperature (°C)	170	170
Dumbbell	Die C	Die C
Test Temperature (°C)	23	23
Hardness Shore A2 (pts.)	67	49
Ultimate Tensile (MPa)	7.56	21.18
Ultimate Elongation (%)	715	542
Stress @ 25 (MPa)	1.43	0.783
Stress @ 50 (MPa)	1.36	1.05
Stress @ 100 (MPa)	1.35	1.69
Stress @ 200 (MPa)	1.75	4.75
Stress @ 300 (MPa)	2.57	10.32
DIN ABRASION		
Abrasion Volume Loss (mm <sup>3</sup> )	418	160
COMPOUND MOONEY SCORCH		
Test Temperature (°C)	135	135
t Value t03 (min)	15.31	26.48
t Value t18 (min)	>30	>30
MDR CURE CHARACTERISTICS		
Frequency (Hz)	1.7	1.7
Test Temperature (°C)	170	170
Degree Arc (°)	1	1
Test Duration (min)	60	60
Torque Range (dN.m)	100	100
Chart No.	654	2084
MH (dN.m)	26.14	18.96
ML (dN.m)	13.8	4.87
Delta MH-ML (dN.m)	12.34	14.09
ts 1 (min)	0.3	1.68
ts 2 (min)	0.36	3.36
t' 10 (min)	0.27	2.4
t' 25 (min)	0.47	5.11
t' 50 (min)	4.14	9.34
t' 90 (min)	37.47	22.54
t' 95 (min)	48.01	26.97
Delta t'50 - t'10 (min)	3.87	6.94

Although the invention has been described in detail in the foregoing

5 for the purpose of illustration, it is to be understood that such detail is solely for that purpose and that variations can be made therein by those skilled in the art without departing from the spirit and scope of the invention except as it may be limited by the claims.